DESIGN, CONSTRUCTION AND TEST
OF A
STEAM AIR-EJECTOR

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DESIGN, CONSTRUCTION AND TEST OF A STEAM AIR EJECTOR

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STEAM AIR-EJECTOR

INTRODUCTION

The study of the steam air-ejector opens up a field which is intensely interesting. This thesis covers, of necessity, only a small area in the search to find something useful to the engineering profession. It is with this thought and hope in mind that we have launched out on new waters of experimentation. It is hoped that our work will not be set aside, but will be carried on by the future students at the Armour Institute of Technology.

The authors desire to express their gratitude and indebtedness to their teacher, Professor George F. Gebhardt, whose deep interest and co-operation have made this report possible.

The subject has herein been presented in two parts:- the first, the general principles and important factors which enter in, and second, an application of these to a concrete example.

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A survey of what work and results of experimentation has already been accomplished is given in part #1. The design of some of the machines, which are already on the market, is also given.

The calculations, design, construction, and testing of a particular apparatus for the removing of air from condensers, when a high degree of vacuum, is desired are given in part #2.

In this day of high efficiency, limited floor space, low maintenance cost, and dependability of machines, the steam turbine, as a prime mover, has, no doubt, come to stay. With the turbine came the demand for condensers of a large capacity and capable of maintaining a high degree of vacuum. It depended chiefly upon the air pump to maintain this vacuum. Hence an air pump of minimum space requirements, highest efficiency, and lowest maintenance cost, is a

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machine which is most desirable. Much has yet to be done before such a machine will be brought forth.

Steam air-ejectors, for removing air have been known and used as early as 1868, but never with the thought of producing a high vacuum, commercially. This was due to the fact that the demand for a high vacuum was created only when the steam turbine became one of the standard prime movers for power plants.

The knowledge of the properties of steam at this time was based mainly on the classic investigation of Regnault.

Steam air-ejectors operate on the dry air principle. It is desirable that they be highly developed because of their mechanical simplicity, ruggedness, absence of moving parts, (and hence the absence of lubrication), and durability, (because of their design and construction).

The Radojet Air Pump, which is built by the

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C. H. Wheeler Manufacturing Company, is perhaps one of the most advanced air-ejectors that is on the market at the present time.

The Radojet consists of two steam ejectors working in series; the upper ejector being called the first stage, and the lower one, the second stage.

Referring to Fig. #1, the live steam is delivered at 'L', and from there it passes through a strainer #1, through pipe #2, auxiliary steam valve #3, strainer #4, and into the expansion nozzles #5. It then crosses the suction chamber #6 of the first stage ejector. This chamber is in direct communication with the condenser through the opening #S.

The steam expands in the nozzles, leaving them with a very high velocity. While passing the suction chamber #6, it entrains the air and vapors, which are to be compressed up to the pressure of the atmosphere.

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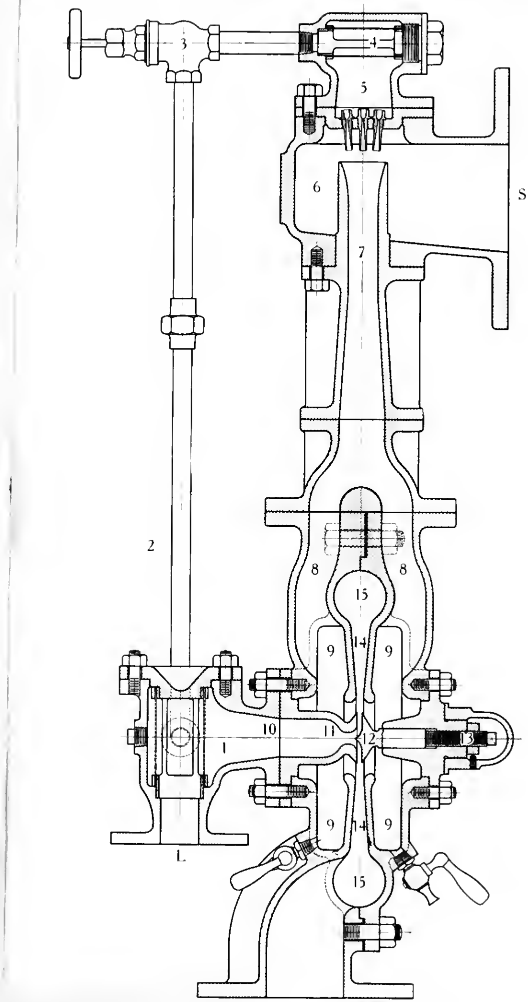
The mixture then passes into the diffuser #7. Here it is discharged at a higher absolute pressure than that of the air entering at 'S'. It then enters into a double passage #8, which communicates with the suction chambers #9 of the second stage. These two suction chambers are annular, giving the commingled gases a large entrainment surface.

Steam is simultaneously delivered through the strainer #1 into the passage #10. This communicates with annular expansion nozzle, which is formed between the two circular discs #11 and #12. Disc #12 may be adjusted by means of screw #13, to vary the cross section of the nozzle passage. Hence the expansion ratio of the steam is changed.

The steam, delivered radially by the annular nozzle #11 and #12, expands leaving it as a jet of high velocity in the form of a disc. In passing across the suction chamber #9, it entrains


3
4
5
6
S
7
2
8
8
15
9
14
9
10
11
12
13
1
9
14
9
L
15

the air and steam coming from the first stage. The commingled air and steam passes into the annular diffuse #14, and the mixture is then compressed up to atmospheric pressure. The mixture is then discharged into casing #15, which has a discharge opening #D.

The steam nozzles and the diffuser are designed scientifically to give the highest overall efficiency. The nozzles of the first stage are bronze and those of the second stage are of a bronze steel. The diffusers of bronze and accurately machined. In the smaller sizes, the diffusers are a part of the casting, while in the large sizes the diffusers are secured to a cast iron casing by bolts. These form a ground metal to metal, joint with the casing.

The strainers ahead of the nozzles are easily removed for cleaning.

Figure #2 shows a method of discharging the mixture into a tank supplied with fresh water

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for the boiler. The steam contained in the mixture is condensed and the heat transmitted to the boiler feed water, raising its temperature. The air frees itself from the raising water and escapes through a vent to the atmosphere.

Another design of an ejector air-pump, or steam air-ejector, is being put on the market. After many months of arduous research work, during which time many set-backs and innumerable difficulties were overcome, the inventor, Maurce Leblanc, evolved a fairly high class pump.

Figures #5 and #6 show the general arrangement of this apparatus. The pump is arranged to work in two stages, steam being admitted to the second stage by the valve 'C'. Immediately 'C' is opened, steam fills the annular space behind the nozzle plate and finds its way into the throats of the group of nozzles,

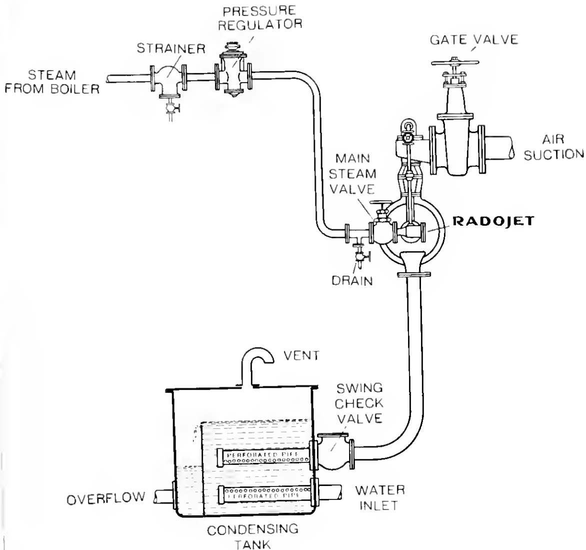
PRESSURE
REGULATOR
STRAINER
STEAM
FROM BOILER
GATE VALVE
AIR
SUCTION
MAIN
STEAM
VALVE
RADOJET
DRAIN
VENT
SWING
CHECK
VALVE
PERFORATED PIPE
PERFORATED PIPE
OVERFLOW
WATER
INLET
CONDENSING
TANK

FIG. 2

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'Y', which are attached to this plate. The method of supplying the first stage with steam is readily seen from the picture. The pump is connected to the condenser at the branch 'D', which is the air inlet. At the entrance to each of the steam spaces back of the nozzles, fine wire gauze strainers are fitted to prevent any foreign matter, which may have primed over from the boiler, from entering the nozzles. A stoppage of one or two of the nozzles might mean a loss of the vacuum.

The nozzles are securely locked to the nozzle plates. The mixture of air and steam is discharged at the mouth of the cone 'Y', and lead away to a feed water heater of the open type. In this manner a part of the heat of the steam is reclaimed.

To start the pump, the valve 'C' is opened and a certain degree of vacuum is attained in the condenser. When the needle of the vacuum

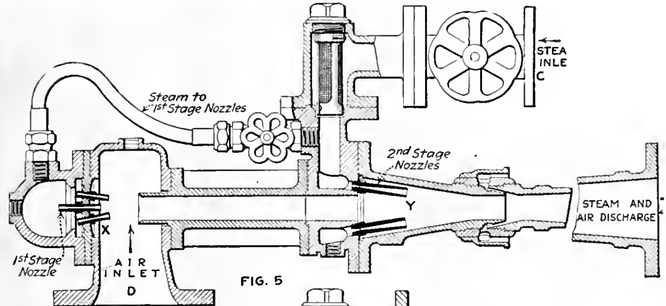
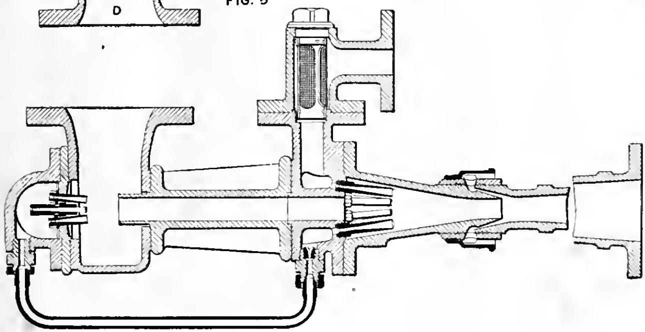

STEA
INLE
C
Steam to
1st Stage Nozzles
2nd Stage
Nozzles
Y
STEAM AND
AIR DISCHARGE
X
1st Stage
Nozzle
AIR
INLET
D

FIG. 5



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gauge becomes stationary, the inlet steam valve for the second stage is opened and the maximum degree of vacuum is obtained in a short time.

A very important factor in this type of pump is the absence of moving parts.

This Leblanc air pump, although apparently having a rather high steam consumption is really very efficient and economical. This machine gives back about ninety-five percent of the original heat of the steam.

Figure #7 shows the form which the steam jet is though to take, upon expansion into a high vacuum. The steam, issuing from the mouth, expands and contracts alternately. It ultimately assumes a constant cross sectional area. Leblanc found that a number of these nozzles grouped together gave far better results than a single nozzle with a throat area equal to the aggregate area of the smaller nozzles. The

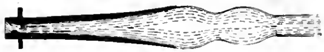

FIG 7

reason for this is that the alternate increasing and decreasing of the cross sectional area of the jets is minimized by the contact of one steam jet with next, when groups of nozzles are used. This helps considerably to increase the surface available for entrainment of the air.

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DESIGN OF PRIMARY NOZZLE (theoretical)

The design of the first stage nozzle resolves itself into the following problem:-

Assume a diameter of throat opening and back pressure at end of nozzle. Having given the available steam pressure, follow through the calculations and design of a nozzle. Compare these calculated dimensions with the required ones for such a nozzle.

Hence, given 100# gauge, (or 115# abs.), initial pressure, .94# abs. back pressure and 1/4" diameter throat. Initial steam assumed as dry.

Dia. = 1/4"

B_2 = .58 x 115# = 66.7# abs. press. in the throat.

P_1 = 100# + 15# = 115# abs.

P_7 = 28# vacuum = 1.92 x .49 = .94# abs.

Area of 1/4" throat = .4915 sq. in.

= .000341 sq. ft.

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$$V = 224\sqrt{H_1 - H_2}$$

where, H_1 = heat at 115# = 1188.7 B.T.U.

" H_2 = heat at 66.7# = 1145 B.T.U.

Assuming adiabatic expansion,

$$V_2 = 224\sqrt{1188.7 - 1145} = 1480 \text{ ft./sec.}$$

From Moller diagram,

V_1 = 3890 ft./sec. velocity.

X_2 = .964

'S' at 66.7# = 6.48 (from steam tables)

.964 x 6.48 = 6.25 cu. ft./#

also

$V_8 = 224\sqrt{H_1 - H_8}$ (where H_1 at 115# &
" H_8 at .94#)

$$= 224\sqrt{1188.7 - 885}$$

= 3890 ft./sec. (check)

E_1 = 778 (1188.7 - 1145)

= 34400 ft./# of energy in the steam.

A = WS/V

where $_1$A = area in sq. ft. of nozzle opening.

" W = wt. of steam,

" S = specific volume

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where V = vel. ft./sec.

$$.000341 = \frac{W \times 6.49}{1480}$$

$$= .0778\# \text{ steam/sec.}$$

or .0778 x 3600 = 284# steam/hr.

This is theoretically the amount of steam which will pass through the nozzle per sec. by expanding from 115# abs. boiler pressure, to 66.7# pressure in the throat.

The areas, or diameters, of the different sections at the respective pressures of 66.7#; 40#; 14.7#; 8#; 4#; 2#; & .94# (discharge press.) were obtained in the following manner; i.e. at 8# pressure.

$$A = \frac{.0778 \text{ (lbs. steam/sec.)} \times S \text{(specific vol. @ 8\#)}}{3060 \text{ (vel. in ft./sec.)}}$$

$$= .475'' \text{ dia.}$$

$$= .00121 \text{ sq. ft. area.}$$

This method gives a diameter of 1.156" at .94# back pressure. There are losses which enter in and change the quality, volume, and velocity

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of the steam. It is necessary to allow for these in the working nozzle. The calculations for this nozzle will be given later.

The total heat, quality and velocity used in these calculations were obtained from the Moller diagram, (the velocity being checked by calculation).

$$F = \frac{W \times V}{g}$$

where F = no. foot-lbs.

" W = wt. of steam,

" V = vel. in ft./sec.

" g = 32.2 ft./sec./sec.

$$F \text{ (at 4\#)} = \frac{1 \times 3370}{32.2}$$

$$= 104.6 \text{ ft. -lbs.}$$

also

$$d = \sqrt{\frac{144 \times 4}{3.1416}} \times A,$$ (where A = area in sq. ft. of cross section.)

$$= 13.65\sqrt{.00705}$$

$$= 1.15'' \text{ dia. at discharge.}$$

P # PRESS.	H TOTAL HT.
P_1 115#	1188.7
P_2 66.7#	1145
P_3 40#	1108
P_4 14.7#	1039
P_5 8#	1002
P_6 4#	961
P_7 2#	923
P_8 .94#	.886

THEORETICAL NOZZLE.

P # PRESS.	H TOTAL-H'T.	x QUALITY	u SP. VOL.	$S = xu$ ACT'L VOL.	V VEL. FT/SEC	E FT-LB	A SQ. FT	d DIA-IN.	F POUNDS
P_1 115#	1188.7	1.00	3.88	3.88	0	0	∞	∞	0
P_2 66.7#	1145	.964	6.49	6.25	1480	34,400	.000341	.25	46.0
P_3 40#	1108	.935	10.49	9.8	2010	62,800	.000406	.275	62.4
P_4 14.7#	1039	.886	26.8	23.75	2740	115,900	.00076	.377	85.1
P_5 8#	1002	.862	47.27	41.5	3060	145,200	.00121	.475	95.0
P_6 4#	961	.837	90.5	75.7	3370	177,000	.00209	.625	104.6
P_7 2#	923	.813	173.5	141	3643	213,000	.00370	.832	113.2
P_8 .94#	.886	.791	350.8	274	3890	234,500	.00716	1.156	120.7

VAK. 4-25-18.

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DESIGN OF WORKING NOZZLE

The design of this nozzle takes into consideration the increasing quality of the steam, due to the friction in the nozzle.

The length of the nozzle will not change from the theoretical.

This nozzle, like the theoretical one, presents the following problem:

d_1 = 1/4" = .4915 sq. in. = .000341 sq.ft.

P_1 = 100# ga. = 115# abs.

P_2 = .58 x 115# = 66.7# abs. pressure in throat.

P_8 = 28" vacuum = 1.92 x .49 = .94# abs. pressure.

The energy loss is converted into heat and hence tends to dry out the steam. Assuming a 10% energy loss and calling this loss = 'y'

$$V = 224 \sqrt{(1 - y)\ (H_1 - H_2)}$$

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where H_1 = heat at 115# = 1188.7 B. T. U.

" H_2 = heat at 66.7# = 1145 B.T.U.

$$V = 224 \sqrt{(1 - 0.1)\ (1188.7 - 1145)}$$

$$= 224 \sqrt{.9 \times 43.7}$$

= 1405 ft/sec. vel. of steam in the entrance.

QUALITY OF THE STEAM AT VARIOUS POINTS.

X_1 = real quality,

X_8 = theoretical quality

r_8 = latent heat of vaporization

$$X_1 = X_8 - I_8 = X_8 - y\ (H_1 - H_8)$$

Increase in quality;

$$= \frac{.1 \times (1188.7 - 886)}{1035.6}$$

$$= .0294$$

Real quality = .0294 - X

= .0294 - .791

= .810 for the discharge quality.

FOOT-LSB. OF ENERGY IN THE STEAM.

$$E = 778 \times \sqrt{(1 - y)\ (H_1 - H_2)}$$

$$= 778 \times \sqrt{(1 - 0.1)\ (1188.7 - 1145)}$$

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= 31,000 ft. lbs. of energy at throat

AREA IN SQ. FT. OF NOZZLE

$$A_8 = \frac{WX_1 \times U}{V}$$

where A = area in sq. ft.

" W = wt. of steam passing through nozzle.

" X_8 = quality of steam (real).

" U_8 = specific volume of steam at .94#

$$A_8 = \frac{.0778 \times 81 \times 350.8}{3760}$$

$$= .00588 \text{ sq. ft.}$$

but, $A_1 = 1/4 \times 3.1416 \times d^2 = .758d^2$

$$d = \sqrt{\frac{.00588}{.785}}$$

$$= .0865 \text{ ft. dia.}$$

= 1.038"; say 1" at end of nozzle.

FOOT-LBS. OF ENERGY

$$F = \frac{W\ V}{g}$$

$$= \frac{.0778 \times 3760}{32.2}$$

= 116.7 ft. lbs.

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LENGTH OF NOZZLE.

$'L' = \sqrt{15 \times a}$ where 'a' = dia. at throat.

$= \sqrt{15 \times .25''}$

= 1 & 15/16" length from throat.

P PRESS (ABS)	V_1 VEL FT/SEC
P_2 64.7#	1405
P_3 40#	1908
P_4 14.7#	2590
P_5 8#	2900
P_6 4#	3230
P_7 2#	3445
P_8 94#	3760

ACTUAL NOZZLE.

P PRESS (ABS)	V. VEL. FT/SEC	E FT. LBS.	x QUALITY	A AREA, SQ.FT.	d DIA. INCHES	F POUNDS.
P_2 66.7#	1405	31,000	.9688	.000341	.250	43.6
P_3 40#	1908	56,500	.9416	000404	.275	59.2
P_4 14.7#	2590	104,200	.9014	.000719	.363	80.5
P_5 8#	2900	130,600	.8809	.001027	.515	90.1
P_6 4#	3230	159,300	.8597	.001863	.584	100.3
P_7 2#	3445	191,700	.8390	.003275	.776	106.9
P_8 .94#	3760	210,600	.8100	.00588	1.038	116.7

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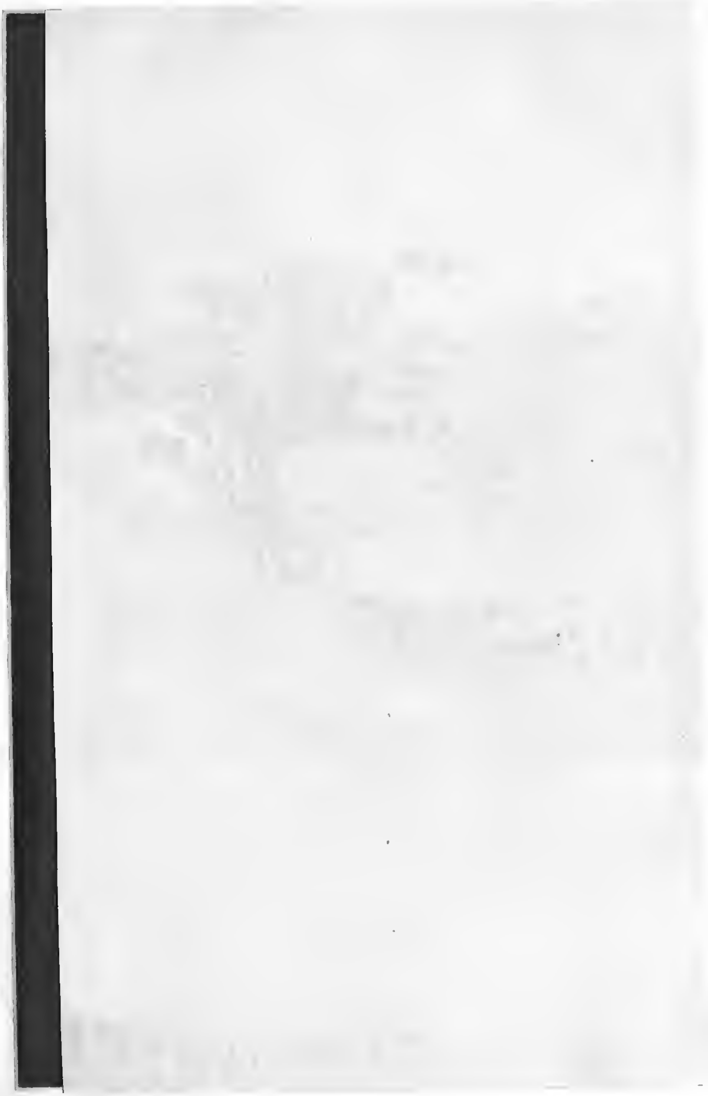

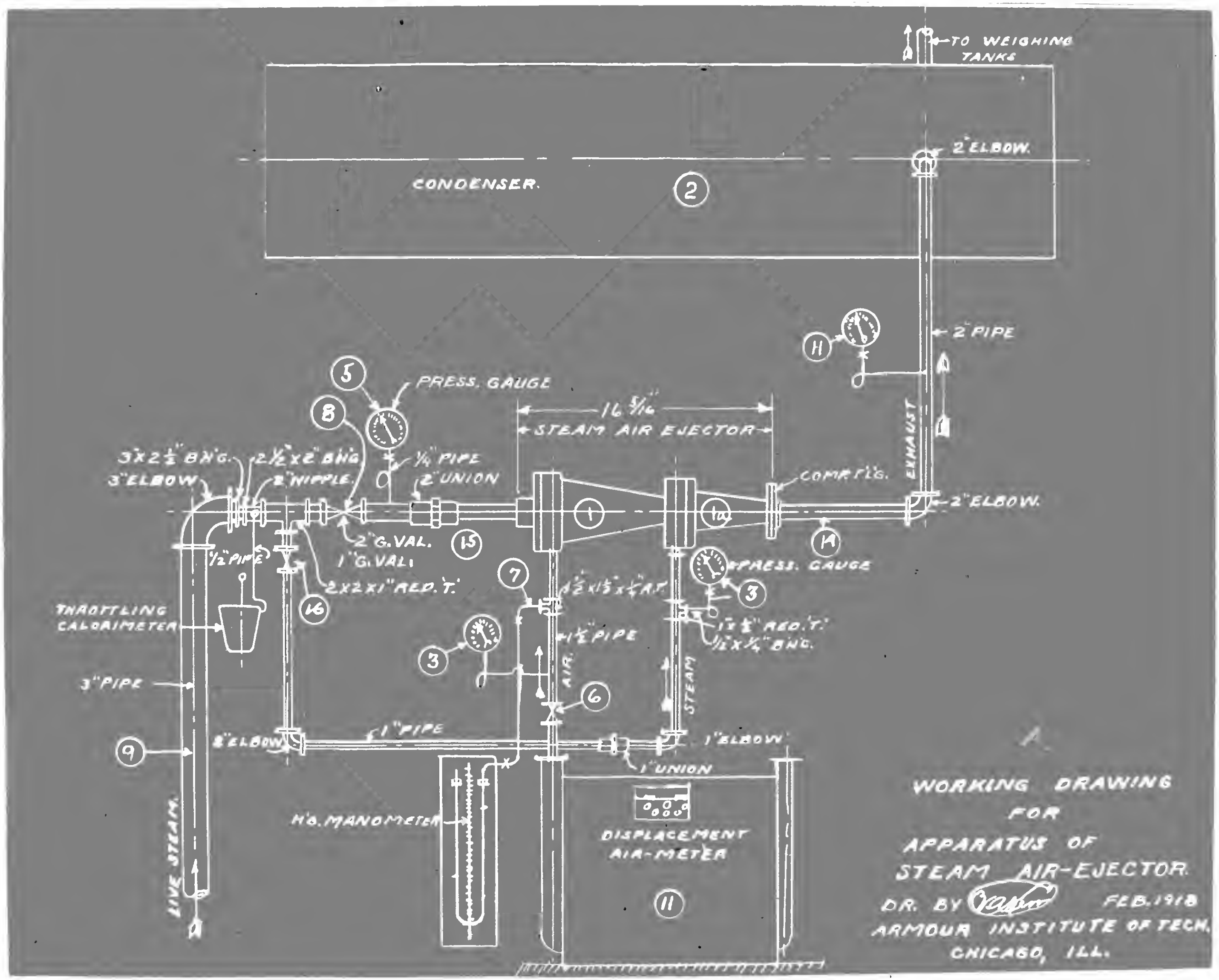

TO WEIGHING TANKS
2" ELBOW.
CONDENSER.
2
2" PIPE
H
EXHAUST
5
PRESS. GAUGE
8
16 5/16"
STEAM AIR EJECTOR
3"x2 1/2" B.H.G.
2 1/2"x2" B.H.G.
3" ELBOW
2" NIPPLE.
1/4" PIPE
2" UNION
COMP. FTG.
2" ELBOW.
1
1a
14
2" G. VAL.
1" G. VAL.
15
1/2" PIPE
2x2x1" RED. T.
16
PRESS. GAUGE
3
7
1 1/2"x1 1/2"x1/4" R.T.
1x1/2" RED. T.
1/2"x1/4" B.H.G.
THROTTLING CALORIMETER
1 1/2" PIPE
3
AIR
STEAM
6
3" PIPE
1" PIPE
1" ELBOW
9
1" ELBOW
1" UNION
LIVE STEAM
H_2O MANOMETER
DISPLACEMENT AIR-METER
11
WORKING DRAWING FOR APPARATUS OF STEAM AIR-EJECTOR.
DR. BY
FEB. 1918
ARMOUR INSTITUTE OF TECH. CHICAGO, ILL.

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METHOD OF CONSTRUCTION

The upper combining shell was made of cast iron. The surface of the top joint was turned corrugated to prevent the packing from blowing out. A light cut was taken from the inside of this piece. This lessened the friction of the gases, which are traveling at a high velocity.

The surfaces of the lower joint were turned smooth in order that the joint might not leak when a metal to metal contact was desirable. The inside of the lower nozzle, forming this piece, was turned central with the outer edge of thesteam passage. This outer edge was made with a sliding fit, over the shoulder of the lower combining shell. It was in this manner that the nozzle was centered.

The lower combining shell was finished with a light cut on the inside to reduce friction on the high velocity gases. The outer edge of

STEAM AIR-EJECTOR

the lower nozzle, (on the inner side of the upper combining shell), was finished smooth to exact size.

The upper and lower combining shells were fitted together, by means of the centering shoulder. When the two smooth surfaces came in contact, it left an opening of between 1/64 and 1/100 of an inch all around the circumference of the secondary nozzle. By inserting a packing of a known thickness in the joint, a known width of opening of the nozzle could be obtained. The nozzle was made of brass and filled on the inside to reduce the friction, which causes a loss of energy in the steam. Threads were cut, on the opposite end from the discharge, leading up to the shoulder, so that the nozzle could be screwed tight up against the top plate. By this means washers could be inserted between the shoulder and the top plate, if it was desirable to change the position of the nozzle.

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The calculations show that the nozzle should not be as long as the blueprint calls for. The authors thought that with the extra length of nozzle, a 'rolling action' could be produced on the sides of the jet that would cause a greater entrainment of air. The nozzle is so designed that it could be cut off to the theoretical length, if it is shown through the subsequent tests that the extra length of nozzle is not desirable.

STEAM AIR-EJECTOR
TESTING AND OPERATION

The ejector was set up for testing in the north-east end of the engine room of the Armour Institute of Technology. A plan of the apparatus and its construction is given in the illustration #A_2. In this illustration all the fittings and apparatus are shown to be swung up into the plane of the paper. In illustrations #A_1 and #A_3 the actual apparatus is shown as it was when it was being tested. The live steam pipe, #9 in #A_3, feeds direct from the boiler to the ejector. The steam coming so direct from the boiler, it was permissable to assume that it had a quality of 100%, in the calculations of the tests that follow. This was also assumed in the calculations of the nozzle.

The live dry steam, coming through pipe #9, goes through valve #8 and enters the primary nozzle at #1. It then goes through the ejector and out the exhaust #14. This gives the opera-

tion of the first nozzle alone, assuming that valve #16 is closed.

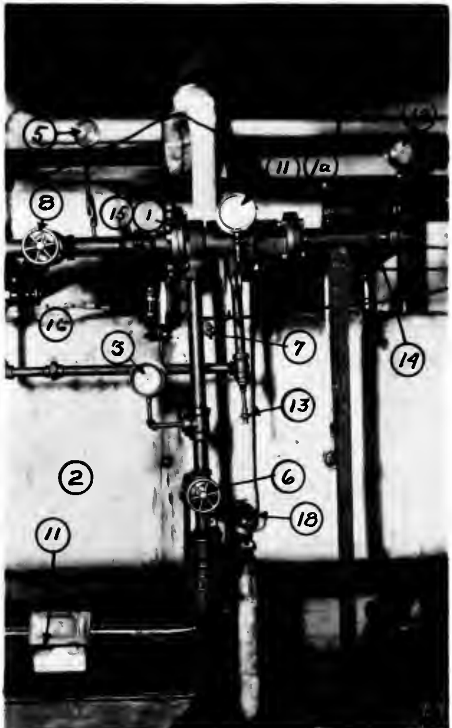
To operate the secondary nozzle alone, valve #8 was closed and the live steam goes through valve #16 and into the secondary nozzle at #1_a. The commingled air and steam then pass out the exhaust #14. To operate both nozzles, valve #8 and #16 are both opened and the steam passing through them comes together again in the lower combining shell, #1_a, and hence to the exhaust. The air that was sucked in came through the pipe #17 and valve #6. This pipe connected on to a displacement air meter #11, which was capable of handling abcut 125 cu. ft. of air per minute. This was sufficient for the ejector.

The exhaust leads to a counter-current condenser, #2, that had been opened to the atmosphere. This virtually makes it an open type of condenser. This was necessary in order that

the air, which had been entrained in the steam, could have an outlet.

A reciprocating pump was situated directly under the condenser. This machine pumped the condensed steam, and a certain amount of air, into either one of two weighing tanks. These tanks were situated about 10 feet back of the condenser and in the south end of the wash and locker room. The live steam, to actuate the pump, was admitted through the valve #18.

In starting to run a test on the ejector as a whole, the steam was first admitted slowly to the line #9, by means of a gate valve and a separator (not shown), so as not to cause 'Water-hammer'. The valve #16 was then cracked open and the drip of valve #19 was allowed to drain off through valve #16, down through the drip-cock #13, and into a pail on the floor. The cooling water from the city mains was then



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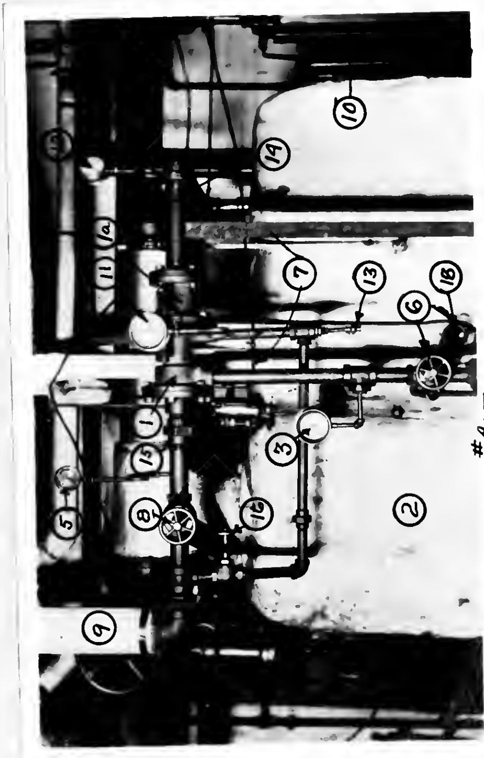

#A2

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started through the condenser. This was forced through by city pressure alone, no pump being used for this circulation. The condenser pump was then started by admitting steam through the valve #18. This pump pumped the condensed steam into the above mentioned tanks which rested on platform scales and were capable of holding about 1800 to 2000 lbs. of water.

When the drip was drained off, the valve #16 was opened full. This let steam to the secondary nozzle. It was thought best to let the steam through the secondary nozzle, first, in order to build up a vacuum in the upper combining shell. The valve #8 was now opened and the steam was admitted to the primary, or first stage nozzle, after having created as high a degree of vacuum as possible. The valve #6, from the air meter, was now cracked open. This was done because the drip from the steam pipe had collected in the air pipe above the

valve #6. In this way the collected water was gradually taken into the ejector and hence into the condenser. When the ejector was well heated up, the air valve, #6, was opened full.

The boiler pressure was read on gauges #4 and #5. The degree of vacuum was read on gauge #3, and also on the manometer, #10. This manometer lead to the suction pipe by means of the tube, #7. The amount of air drawn in was read from the meter at #11. The amount of condensed steam was weighed by means of the tanks on the platform scales in the locker-room.

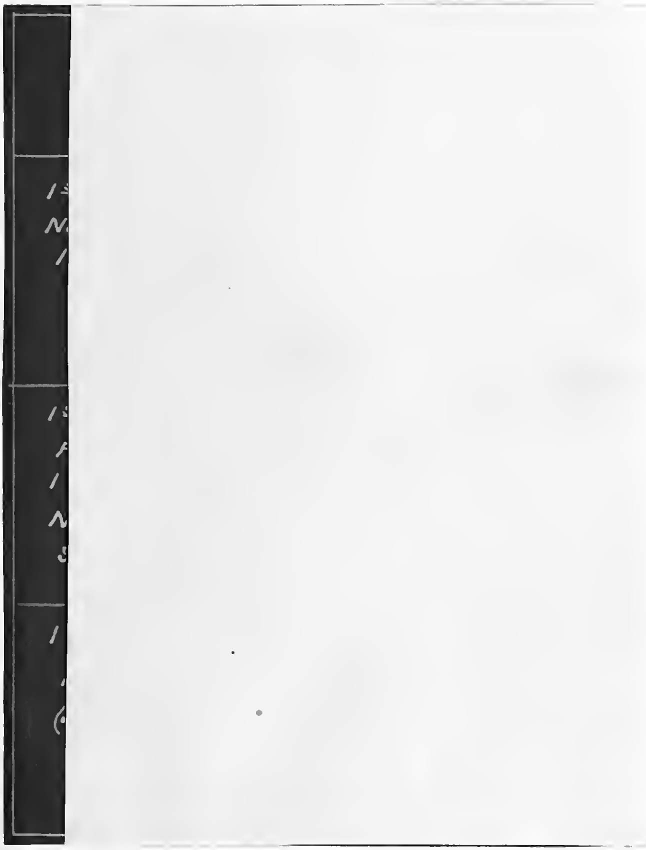
In starting the first test, the secondary was turned on first. Instead of creating the desired vacuum, it caused a back-pressure. The authors thought that the reason for this was that this secondary nozzle had too wide an opening. Because of this, the steam was not directed down, but rather in a course that was diagonal

across the lower combining shell. By following this course, the steam from one side of the nozzle met the steam coming from the other side at a comparatively wide angle. As a result of this there was a combined splash and 'rolling-back' action produced, causing the steam to build up pressure in the upper combining shell.

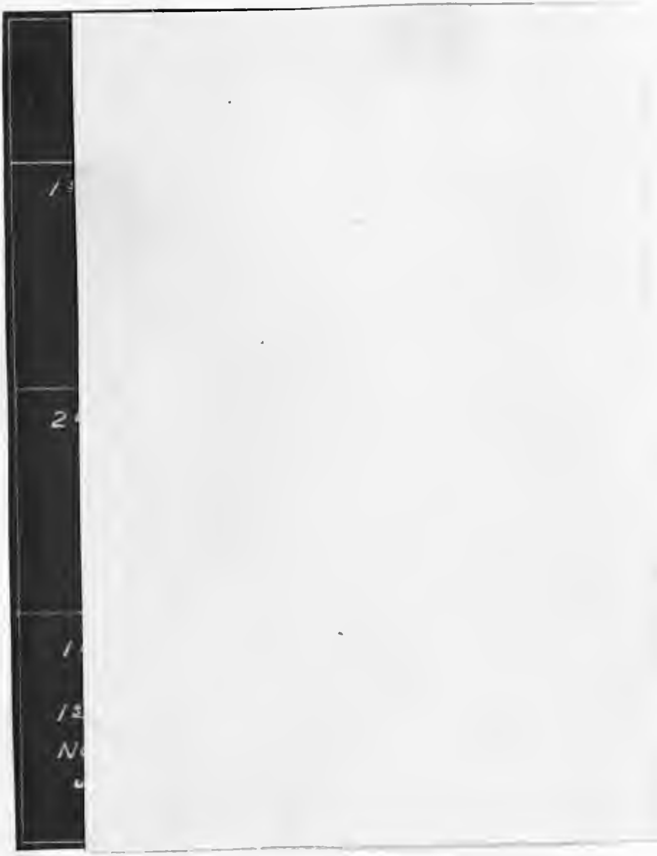
The first nozzle was turned on at this time with the secondary nozzle and a vacuum of about 1" was created. When the secondary nozzle was turned off and the 1st left on running, with wide open valve and under 93# pressure, a vacuum of 2.75" Hg. was created. When the air was shut off fully and maintained about 1" Hg. vacuum and pulled about .47# of air per # of steam. (see log blue print for test #1).

The above results were of little value, hence more elaborate tests and data were unnecessary.

The gasket from the lower joint was taken



CONDITIONS OF OPERATION OF AIR-EJECTOR	STEAM PRESSURE GAGE	FREE AIR CU. FT. PER HOUR	STEAM LBS. PER HOUR	FREE AIR CU. FT. PER LB. OF STEAM	LBS. AIR PER LB. STEAM	VACUUM IN. OF HG.	
						AIR VALVE OPEN	AIR VALVE CLOSED
1ST STEAM JET OPEN NOZZLE LONG 1" DIA. AT OUTLET. (TEST #5)	92	2100	315	6.66	.538	.5	1
1ST & 2ND STEAM JETS FULL OPEN. 1ST NOZZLE LONG NO GASKET AT STUDED JOINT (TEST #4)	103	498	321	1.55	.125	0	3/4
1ST STEAM JET OPEN 1½" PIPE INSERTED (SEE B PRINT NO.) (TEST #6)	103	3810	474	8.03	.65	2½"	5



CONDITIONS OF OPERATION OF AIR-EJECTOR	STEAM PRESSURE GAGE.	FREE AIR CU. FT. PER HOUR	STEAM LBS. PER HOUR	FREE AIR CU. FT. PER LB. OF STEAM	LBS. AIR PER LB. STEAM	VACUUM IN. OF HG.	
						AIR VALVE OPEN	AIR VALVE CLOSED
1ST STEAM JET OPEN 1/4" NOZZLE – LONG (SEE B. PRINT NO.) (TEST #1)	93	2350	404	5.81	.47	1	2.75
2ND STEAM JET OPEN NO GASKET AT STUDED JOINT – NOZZLE ABOUT 1/8" OPEN (TEST #2)	105	2090	190	11	.88	1	2.75
1ST + 2ND STEAM JETS OPEN. (FULL) 1ST NOZZLE. LONG NO GASKET AT STUDED JOINT. (TEST #3)	93	690	471	1.46	.118	0	1

out in order to lessen the opening in the secondary nozzle. This coincided with the above stated ideas that the back-pressure was caused by the steam from the secondary nozzle not having had the right direction in its expansion. The latter was caused by too great an opening in the secondary nozzle.

In this next test no run was taken on the primary nozzle alone as the conditions under which it operated in the first test, were not altered.

The secondary nozzle was made longer by putting the upper combining shell in a lathe and cutting down the upper face of the lower joint and also the outside of the inner edge of the nozzle. Hence it was calculated to give a little less than 1/8" opening, as any less than this would result in wire-drawing. This was done in view of the fact that the steam should be given a better direction, and hence a better

expansion. The latter was to be obtained by having the nozzle longer and of a smaller angle with a geometrical axis of the ejector.

By running the secondary nozzle alone under 105# of steam, it gave a vacuum of 2.75" Hg. with the air entirely shut off. It maintained a vacuum of 1" Hg. with the air valve full open. The secondary nozzle, operating under these conditions, gave better efficiency than the primary nozzle did running alone. The secondary was now a little less than 1/8" open;

This run, by giving better efficiency, which was almost double the other, proved that the authors were working along the right line for the improvement of the ejector.

In the test #3, both jets were full open with a 93# steam pressure. The results of this run show a slight improvement, but it still shows that the two stream lines from the nozzles were causing an eddying, by coming together at too

great an angle. The cause of this was undoubtedly a rolling-back action that destroyed any vacuum which was created by the primary nozzle.

Before run #5 was made, the apparatus was taken down again and the primary nozzle cut off to the calculated length. From the results of run #5, it shows a better efficiency than before, but a smaller capacity. This shows that the theory of the 'rolling-up' action of the steam, due to the extra length of nozzle, did make a greater entrainment of air, but it was done so at the expense of efficiency.

With the results of these tests at hand, the authors thought that the entrainment space was entirely too large to have these stream lines not conflict with each other. This space begins at a point a little below the primary nozzle and extends to the point at which the steam from the secondary nozzle entrains the

STEAM AIR-EJECTOR

comingled air and steam coming from the primary nozzle. The velocity with which the gases go through the combining chamber, and also the manner in which they go down the middle of this space, necessarily leaves a dead space at the sides. With such a space present, the vacuum which had at first been created by the steam, as it first left the nozzle, was destroyed by air and steam backing up into this space. The action is similar to the action which would take place in a hydraulic ram if the cylinder was entirely too large for the piston. That is,like leaving a space between the piston and the walls of the cylinder and then trying to build up a pressure.

To overcome this, it was thought that an additional part could be put into the machine so that the part, which was introduced, would be entirely filled by a stream of high velocity gases. Hence the tendency for a dead space to

form along the sides would be eliminated and the ejector could maintain a high degree of vacuum. If this fast moving stream could be conducted so that it would not have to pass through the trubulent, or back-eddying part, of the lower combining shell, it would help to direct the stream lines in this part of the ejector. It is here that the stream from the secondary nozzle comes together and enters this stream below this point. In this way much of the energy of the streams would not be dissipated by coming together at a comparatively large angle. Although this might cut down the capacity a little, yet, this is not as important to maintain as a high degree of vacuum.

In the assembly blueprint, #2, is shown the method by which this problem was attacked. In this is shown a cast iron collar which fits up against a shoulder at the base of the air passage. This shoulder was made by running an extra

STEAM AIR-EJECTOR

cut down the indise of the upper combining shell, and stopping it at this point. This collar fits with a tight fit in the shell and has sufficient bearing length so that it will always remain in the same position. Inside of the collar it was threaded and a 1 and 1/2" pipe was screwed in until the end of the pipe came flush with the top side of the collar. The upper edge of the pipe and collar was rounded off to give a good entrance for the comming-led air and steam. The pipe was long enough to extend below the back-eddying space in the lower combining shell. It discharged into the center of the high velocity stream of steam coming from the secondary nozzle. In this manner a large part of the dead space, which was a drag on the machine, was placed in a position so that it would not be detrimental to the vacuum created in the ejector.

The collar, holding the pipe, was held in

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place by means of cap-screws inserted from the outside, as shown in the blueprint. The pipe depended solely upon the collar for its support in a central position.

When the steam was turned on the ejector, containing this part, it was found that the secondary nozzle opposed the first, and caused a back pressure. Hence no run could be made with the secondary nozzle.

A run was made, however, on the first nozzle alone. As seen from the log blueprint it gave nearly twice the capacity that any previous run did and also with about an average efficiency. In this run a vacuum of 5" Hg., with the air shut off, and 2 and 1/2" Hg., with the air full on, was maintained steadily through the run.

This run shows that the problem was being attacked along the right line, so far as the first stage was concerned.

The reason for the secondary nozzle's creat-

ing a back pressure was that the steam coming out of this nozzle came at such a comparatively wide angle with the central axis of the ejector. It therefore encountered the pipe, which interfered with the direction of the stream line and caused an eddying and a disturbance. This caused a back pressure and a loss of efficiency.

The authors were lead to the following new design of steam air-ejector, after a study of the results and data obtained from these tests. It is believed that the new design will rectify many troubles, which were prevalent in the earlier machine, and will give much better results.

It is hoped that the following design will be taken up by future students and the machine built with improvements made upon it if possible. Although the present machine is a long way from perfection, yet that degree is obtained only by

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making these necessary steps leading to it.

STEAM AIR-EJECTOR

THE PROPOSED NEW DESIGN OF STEAM AIR-EJECTOR

In this design the authors still adhere to the same principles of the old ejector. To utilize this principle to a better advantage, the design was changed. With the exception of the secondary nozzle, the new design consists mainly of different proportioning of the combining chambers.

Referring to the blueprint of the new design, #4, is the live steam entrance to the primary nozzle, #5. The steam passes through this nozzle entraining the air which is coming through the air inlet, #6. The commingled air and steam pass into the combining chamber, #7. Going from this chamber, the gases pass around the part #8, and are again entrained by the jet #9, in the lower combining chamber. They then pass out through the exhaust #11, into the condenser.

In this design we see the shape of the upper combining shell was reconstructed on the final drawing. The steam and air enter, in this case,

through the rather narrow opening, or throat, of a slightly divergent nozzle. This forms the upper part of this shell. In this manner the entire cross section of the ejector will be filled by high velocity gases, having nearly the same velocity in any one cross section. On the sides, there is, perhaps, about a 5% lag. With this condition prevalent, it would be practically impossible for the air or steam to cause a back pressure by going back next to the walls. In the old design this was undoubtedly the main reason for the low vacuum obtained.

The secondary nozzle, #9, is screwed into the part #8 and connects with the steam passage #2. This part, #8, is a 'V' shaped piece, with the vertex upward, and extending entirely across the lower part of the upper combining shell. The steam passage #2 is bored through from the outside until it just overlaps the middle, and at the outer end of the passage it

STEAM AIR-EJECTOR

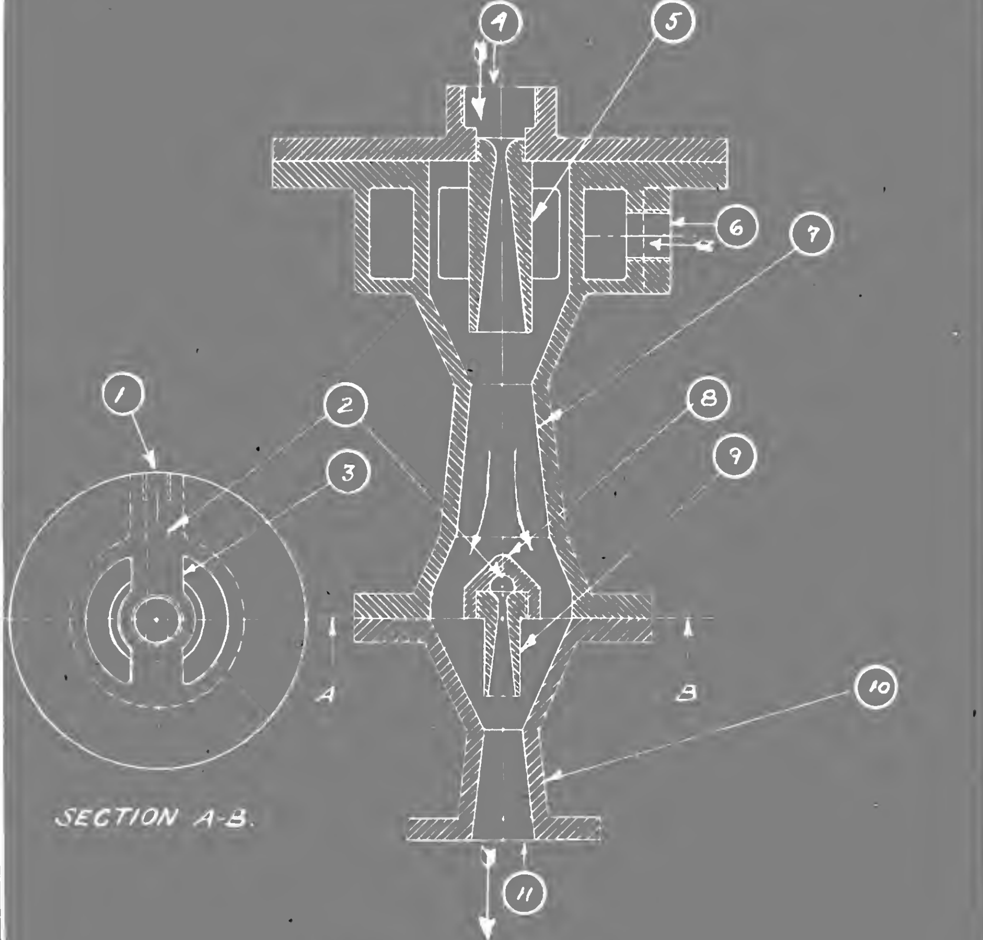
is tapped for the steam line. A hole is drilled and tapped from the bottom, in the middle of part #8, and extends in to meet the steam passage #2. This hole is tapped so that the nozzle may screw in tight.

The steam from the secondary nozzle entrains the vapor and air from the primary nozzle and ejects it into the comparatively small throat of the lower combining chamber #10. This is a slightly divergent nozzle.

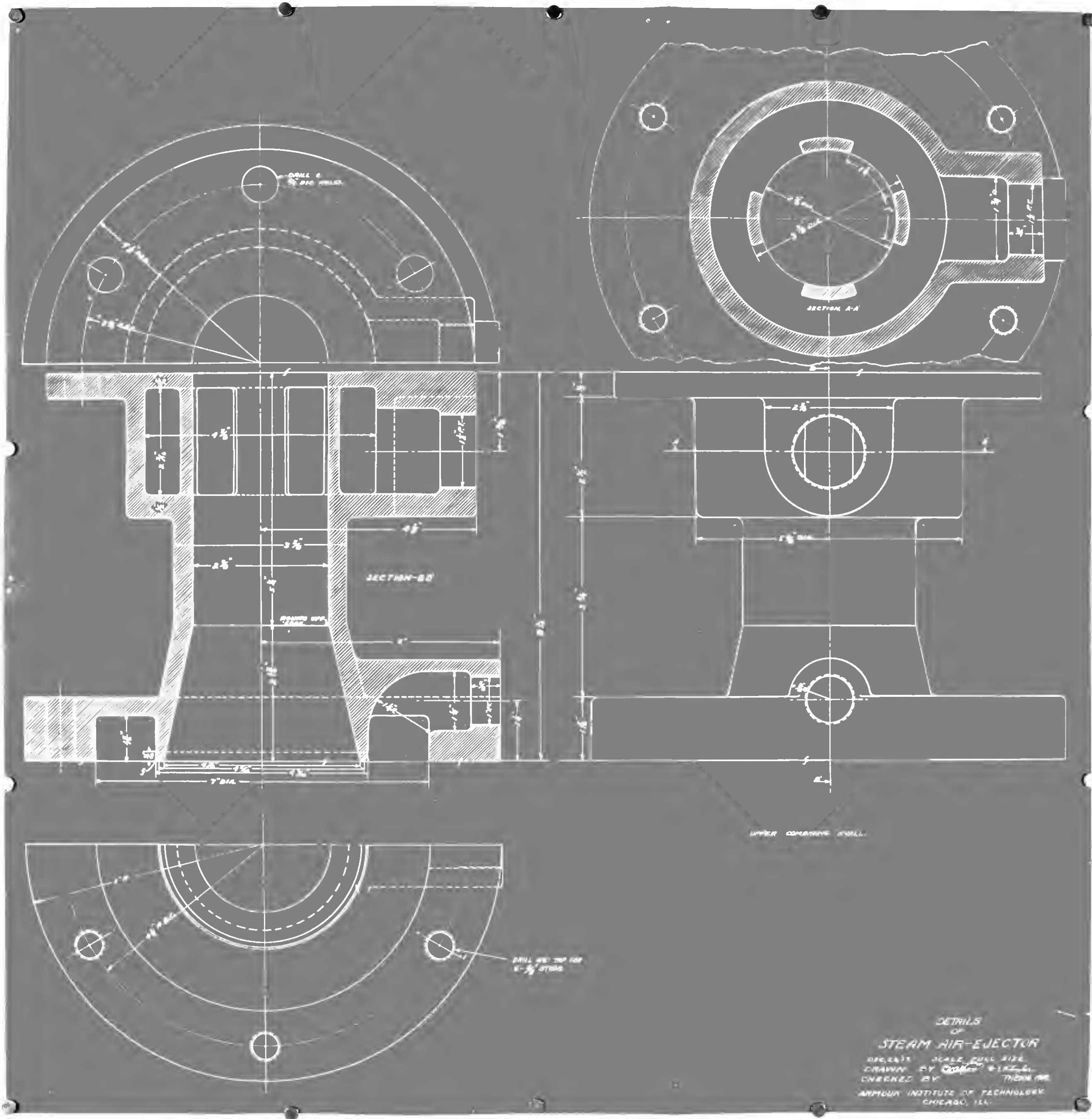
In this manner the secondary nozzle can maintain the vacuum created and expel the mixture against the atmospheric pressure, through #16.

In the analysis of the first design, the authors feel confident that this new ejector will give far better results than the first one did.

The authors regret not having had the time to build this second machine, so that they might have presented positive, instead of negative results.



PROPOSED NEW DESIGN
OF
STEAM AIR-EJECTOR.


SECTION A-A
SECTION-B-B
UPPER COMBINING SHELL
DETAILS
OF
STEAM AIR-EJECTOR
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DRAWN BY
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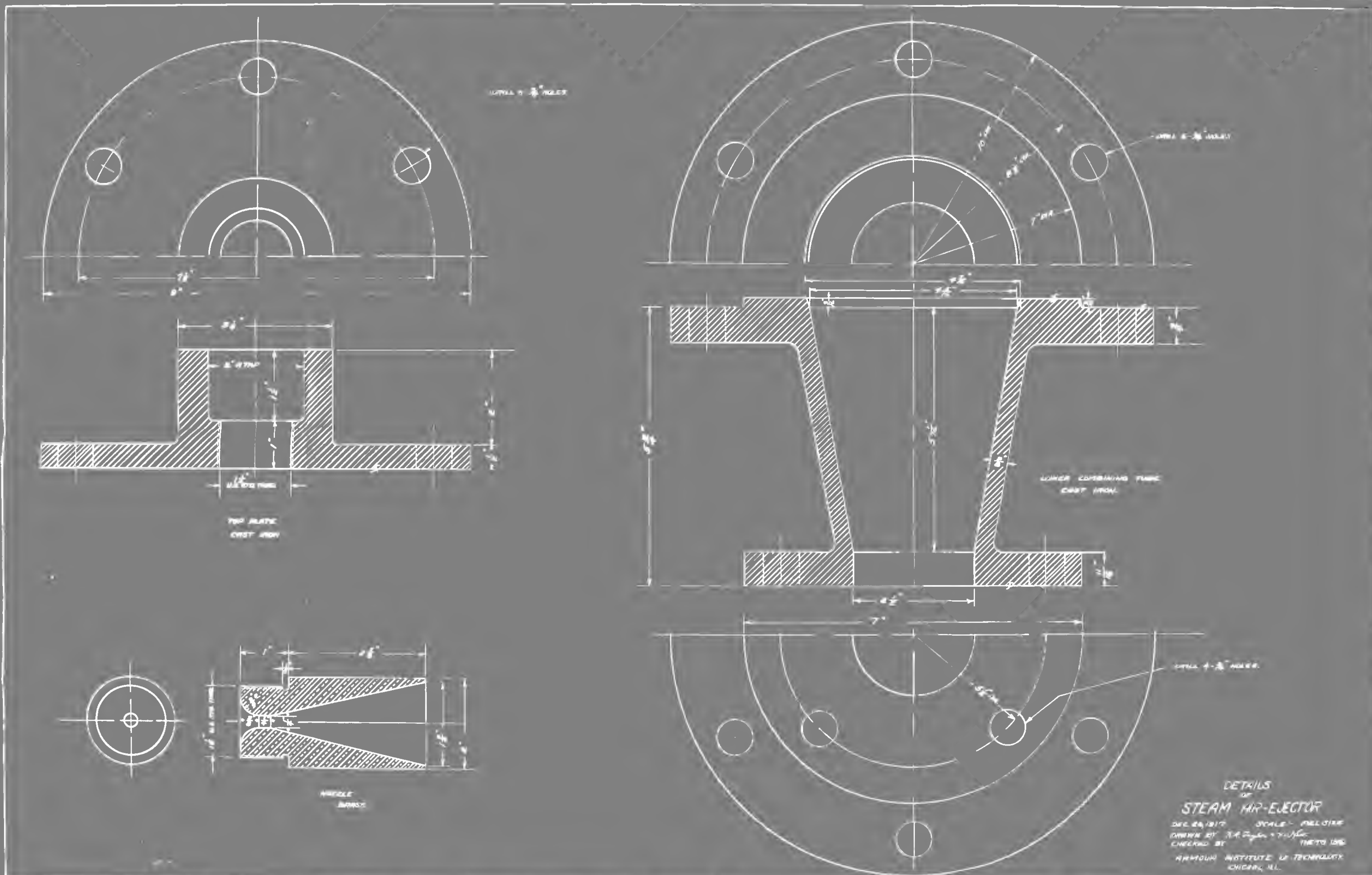
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.


TOP PLATE
CAST IRON
NOZZLE
BRASS
LOWER COMBINING TUBE
CAST IRON
DETAILS
OF
STEAM AIR-EJECTOR
SCALE - FULL SIZE
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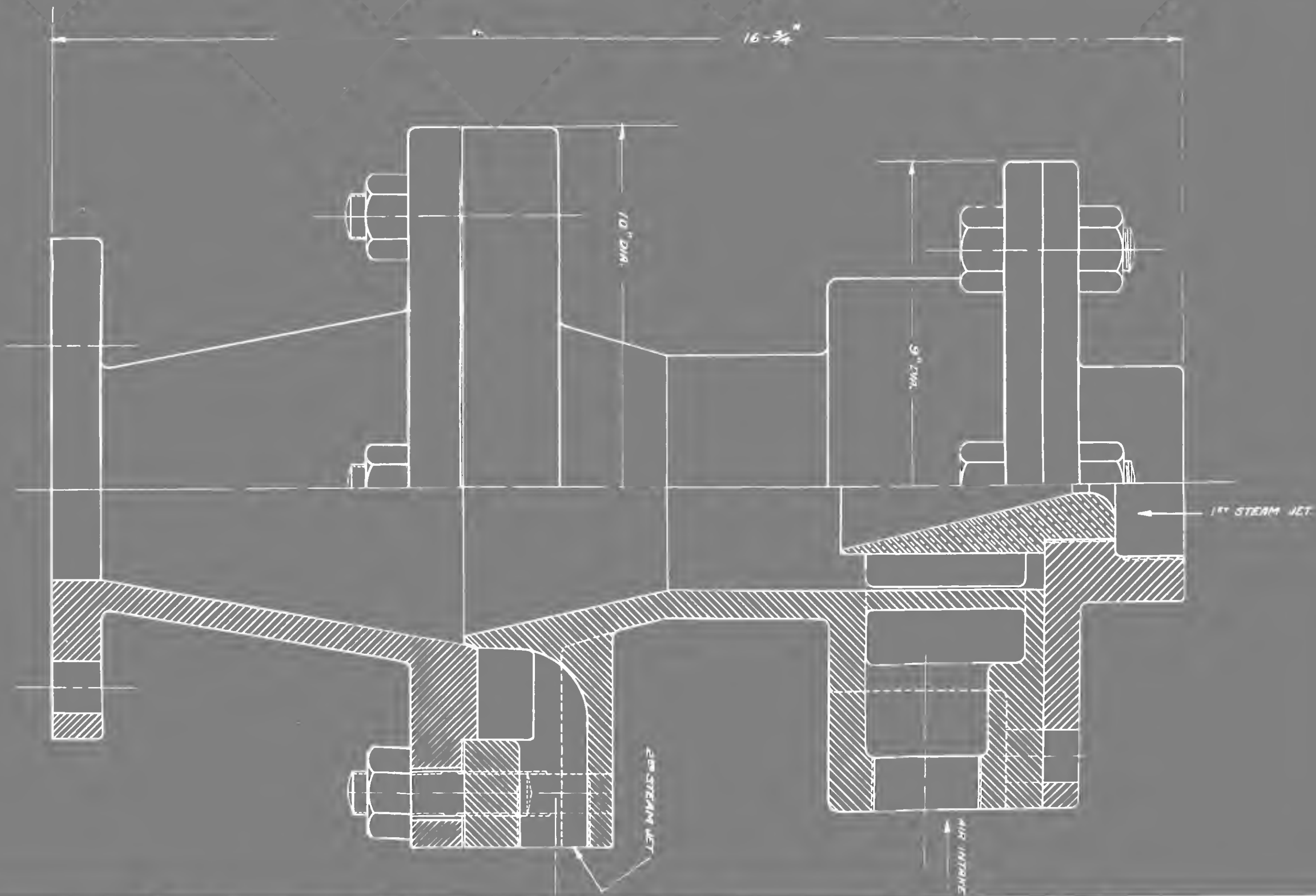
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.



ASSEMBLY
OF
STEAM AIR-EJECTOR
APRIL 1918 SCALE - FULL SIZE
DRAWN BY [illegible] THESIS-1918
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.